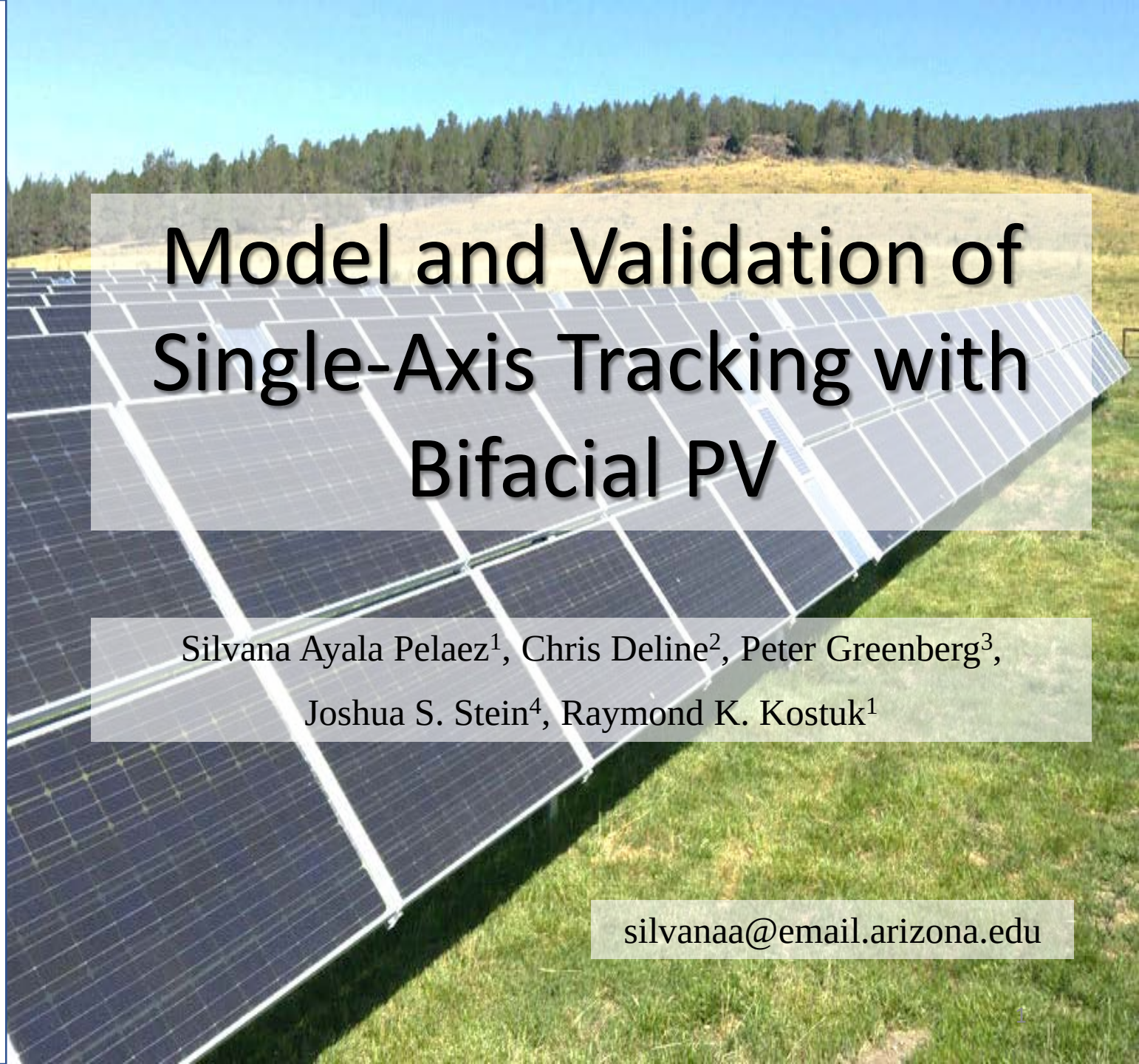

Model and Validation of Single-Axis Tracking with Bifacial PV

Silvana Ayala Pelaez[1], Chris Deline[2], Peter Greenberg[3], Joshua S. Stein[4], Raymond K. Kostuk[1]

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Outline

Single-Axis Tracking Models

- View Factor
- RADIANCE Ray trace

Results for:

- Klamath Falls, Oregon

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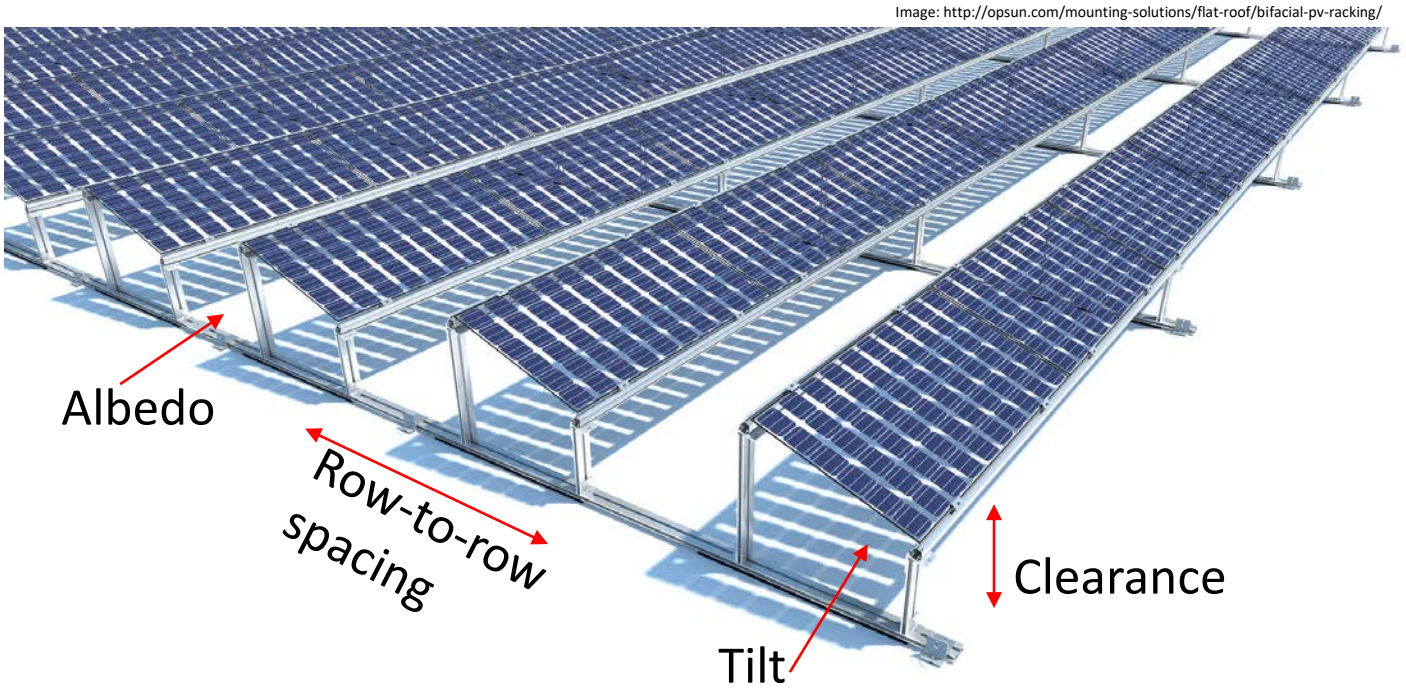
- Adaptive Tracking Angle
- Edge brightening
- Torque tube shading

Modeling Rear Irradiance



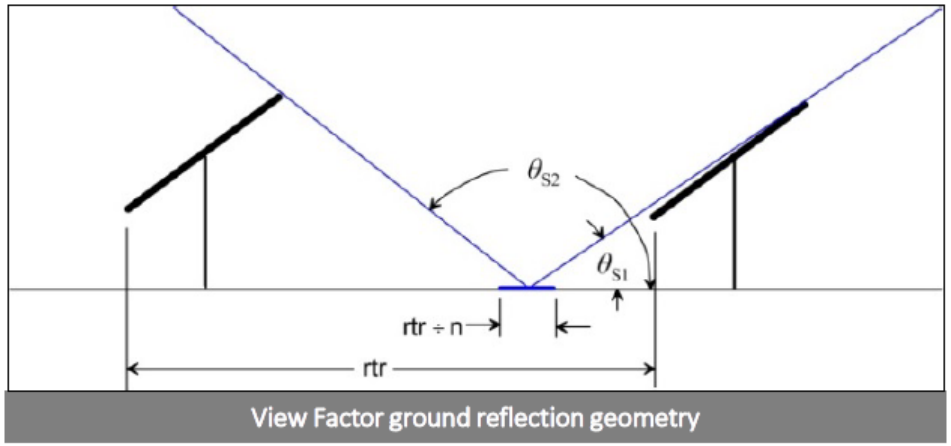
Irradiance Model
Location
Weather
Sky Diffuse Model

Others:
Spacing between cells
#rows, #panels
Mounting Structure
Other scene elements

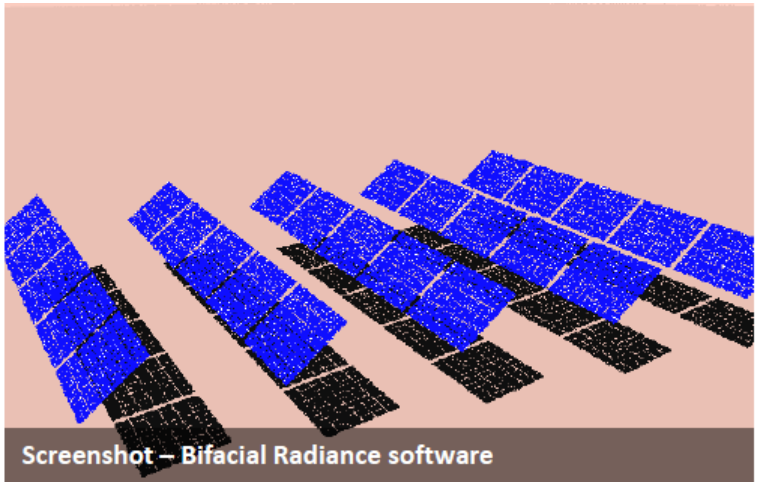
Two open-source tracking models

1. **View Factor model – 8760 hourly gain**
   BifacialVF software release
   gitub.com/NREL/bifacialvf

2. **Ray Tracing – annual bifacial gain**
   Bifacial Radiance software release
   gitub.com/NREL/bifacial_radiance



View Factor ground reflection geometry


Screenshot – Bifacial Radiance software

C. Deline et al, "Evaluation and Field Assessment of Bifacial Photovoltaic Module Power Rating Methodologies ", IEEE PVSC 2016. https://www.nrel.gov/docs/fy16osti/66496.pdf
B. Marion et al., "A Practical Irradiance Model for Bifacial PV Modules", IEEE PVSC 2017 . https://www.nrel.gov/docs/fy17osti/67847.pdf

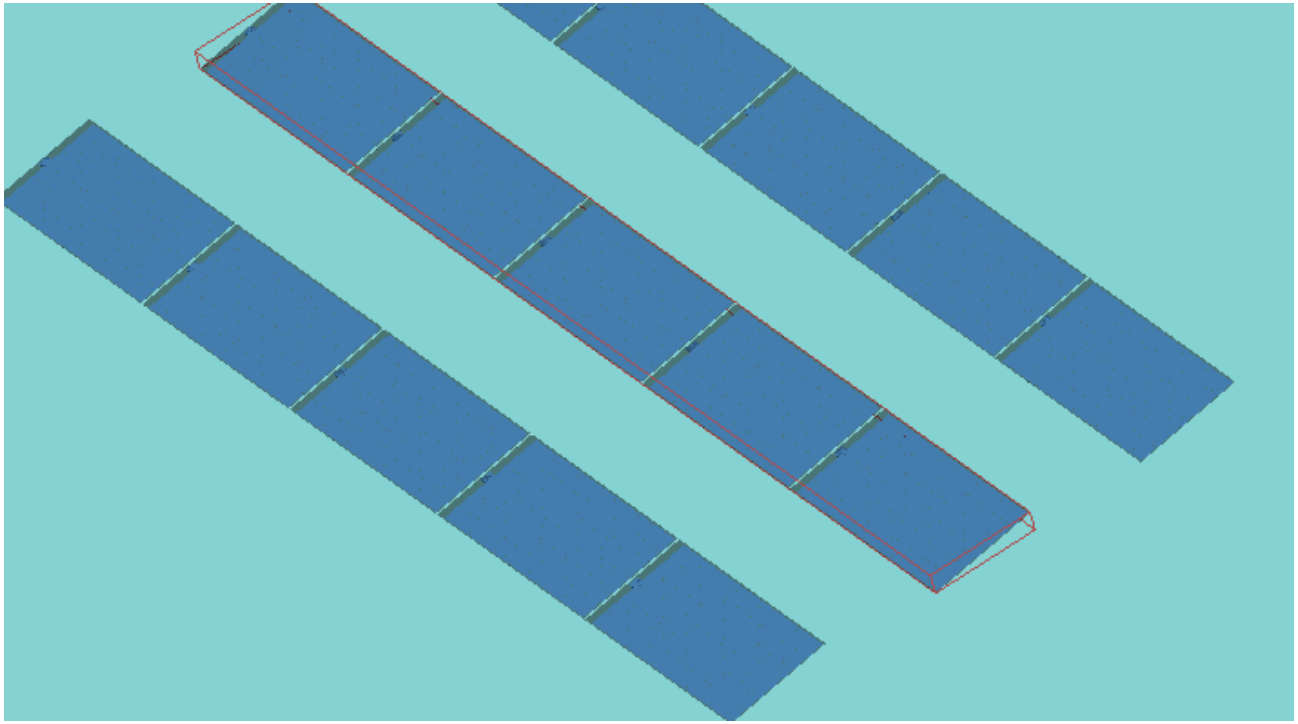
Radiance: Ray-tracing software

Complicated geometries possible, including racking and terrain.

Radiance uses backward ray-trace to evaluate the irradiance (W/m^2) at the modules

Reduces complexity and run-time.

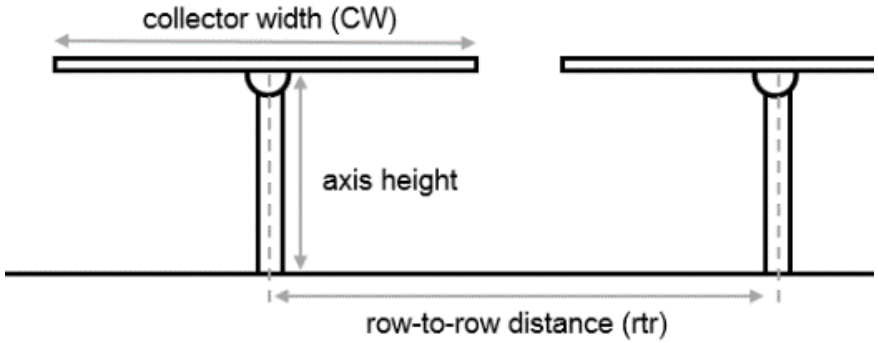
Modules << Sky



Parameters & Metrics

Ground Coverage Ratio

$$GCR = \frac{CollectorWidth}{row - to - row}$$

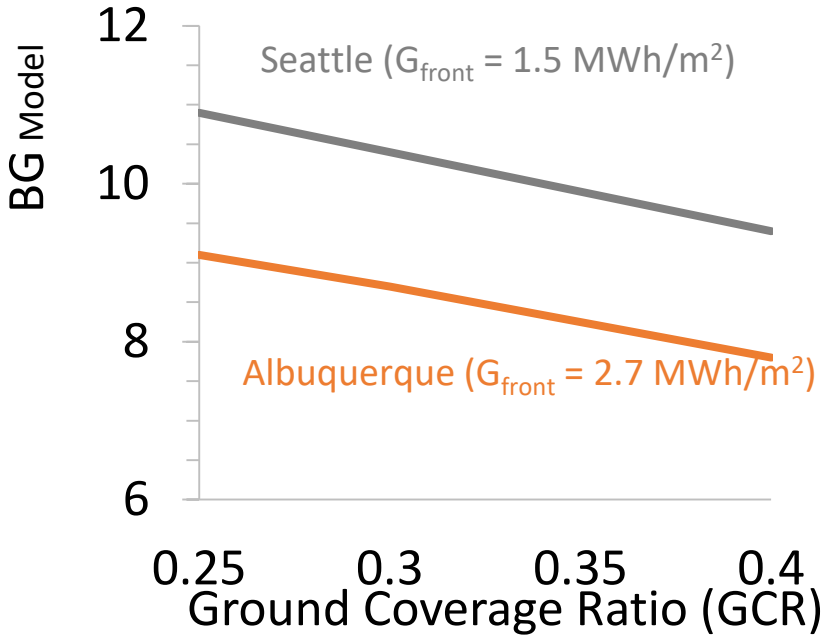


Normalized Axis Clearance

$$H = \frac{axis\ height}{CollectorWidth}$$

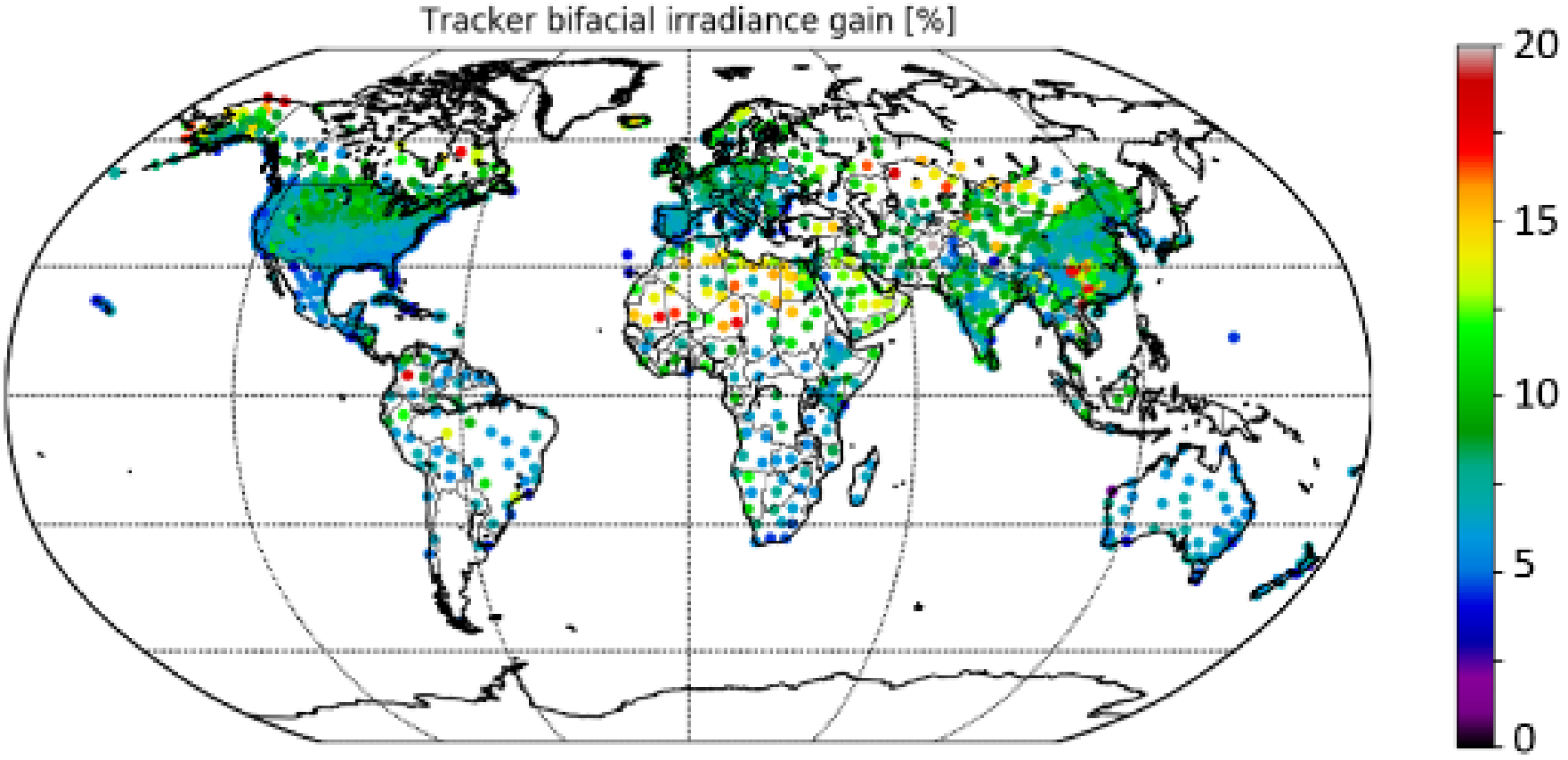
Bifacial Gain (Irradiance)

$$BG_{Model} = \varphi_{Pmp} \times \frac{G_{rear}}{G_{front}}(1 - \eta_{loss})$$



TMY3, Albedo = 0.25 (aged concrete) and *H* = 0.75

BG_{model} for 1-axis tracked system can be as high as 20%. (Typical global average 9%)



Satellite-based TMY irradiance data, and satellite-measured albedo values from NASA
GCR = 0.35, H = 0.75, φ_{Pmp} =100%, and η_{loss} = 0

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Klamath Falls, OR: Tracker System

100 kW of Silfab HIT,
2-up landscape

100 kW of Trina mcSi,
1-up portrait

H = 0.75, GCR = 0.35, Albedo = 0.2 (short grass)

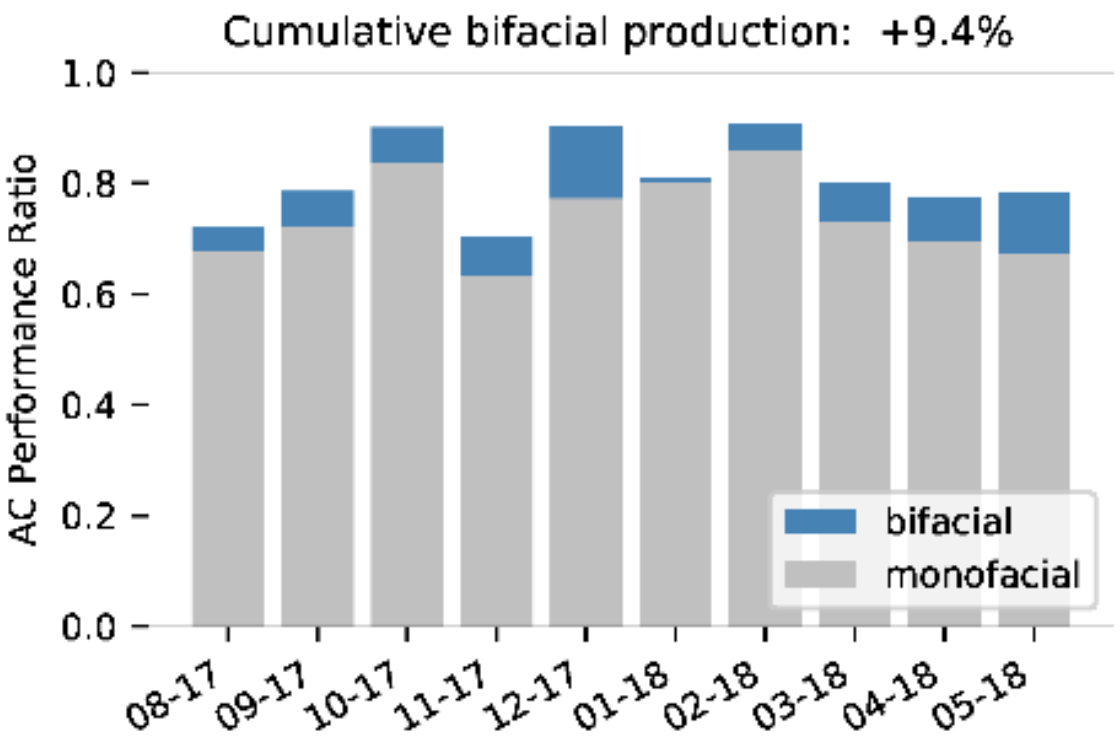
Overall energy gain for a bifacial system is determined by comparing Performance Ratio (PR) [kWh/kW] for both monofacial and bifacial systems

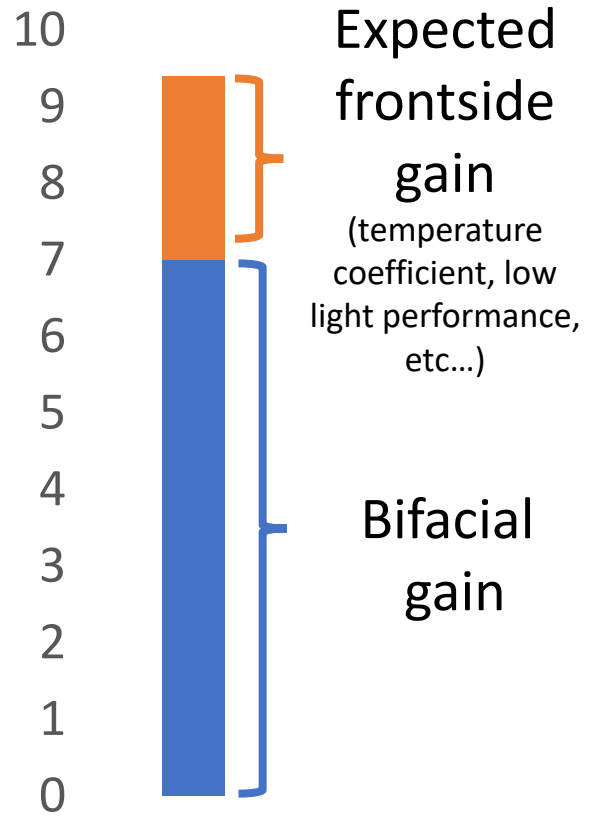
$$BG_{Meas} = 100\% \times \left(\frac{PR_{bifi}}{PR_{mono}} - 1 \right)$$

- Difference in module rating
- Temperature coefficient
- Low light dependence
- Mounting orientation
- Bifaciality

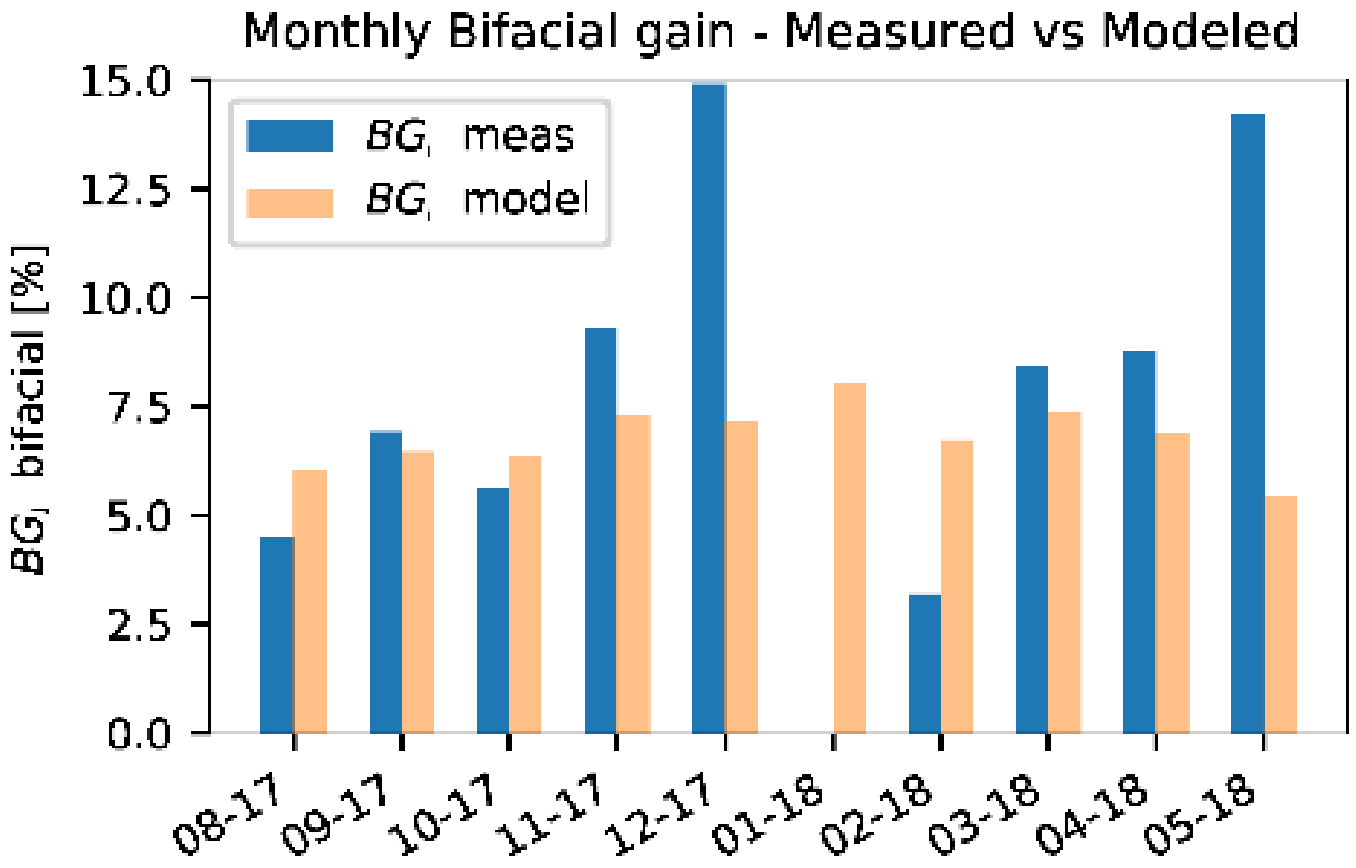
$$BG_{\mathrm{Meas},bifacial} = 100\% \times \left(\frac{PR_{bifi}}{PR_{mono}} \underbrace{\frac{PR_{mono,model}}{PR_{bifi,model}}}_{\text{Correction Factor}} - 1 \right)$$

Although field IV curve measurements indicate comparable front-side capacity for the two systems, the measured PR was on average 9.4% higher for the bifacial system than for the monofacial system.





BG_{Model} is 6.7%close to the measured BG_{Meas} of 7%.



Some variability, particularly on snowy winter months.

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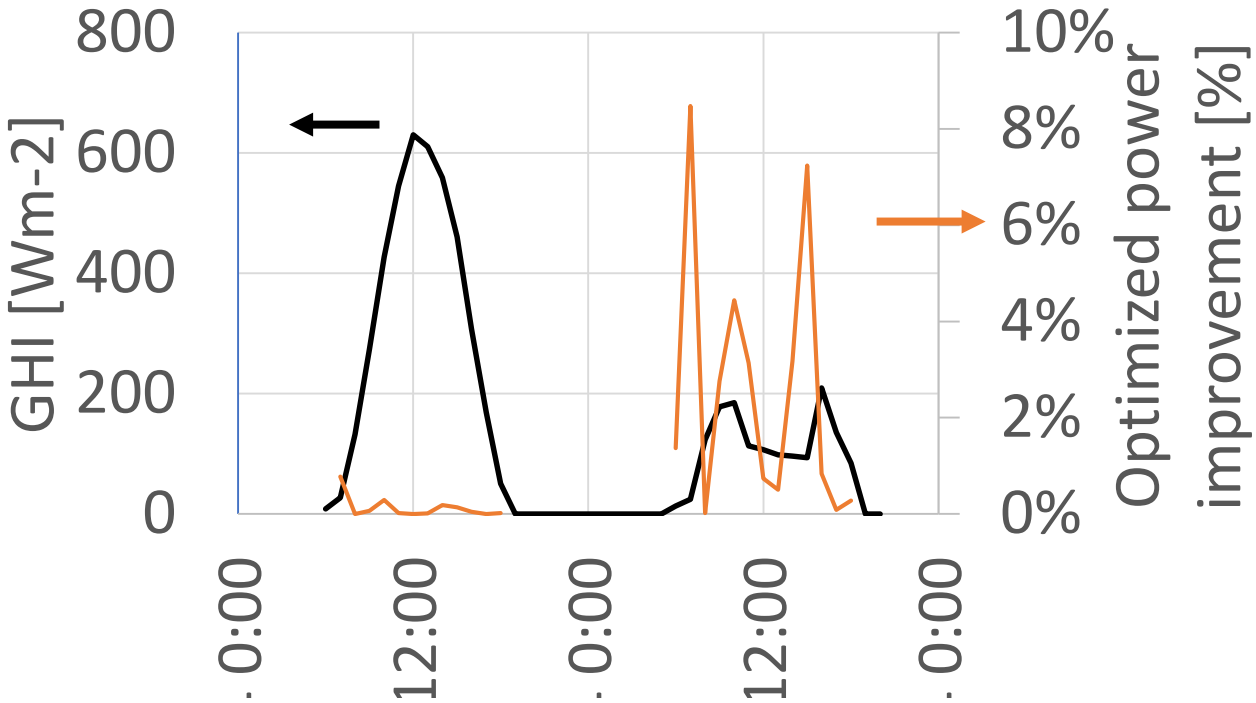
Adaptive Tracking Algorithm for Bifacials

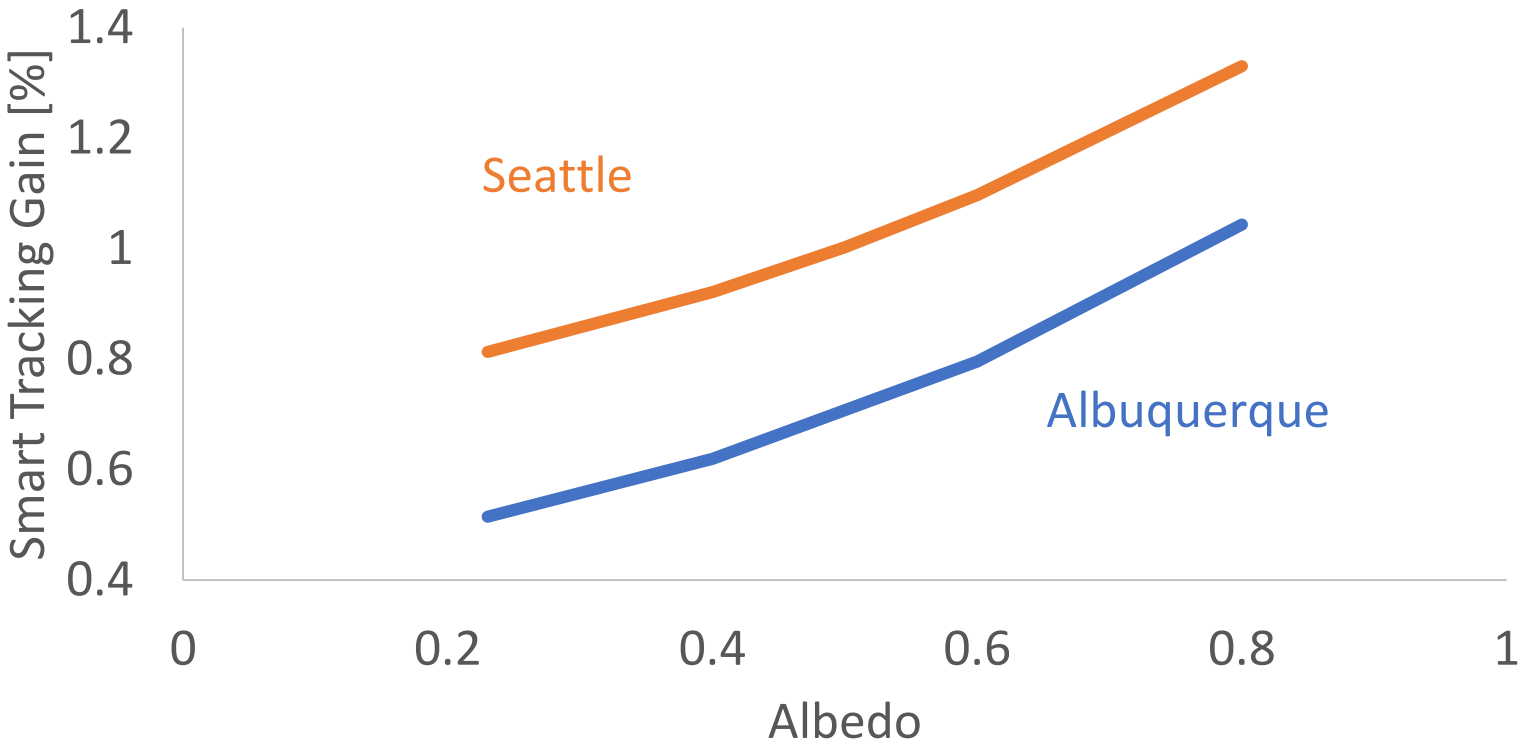
During cloudy conditions, moving the tracker to horizontal can increase energy yield up to 1% in monofacials.

*Optimal tilt angle can depend upon sky conditions and is not always horizontal



N. A. Kelly and T. L. Gibson, "Increasing the solar photovoltaic energy capture on sunny and cloudy days," *Sol. Energy*, vol. 85, no. 1, pp. 111–125, 2011.
M. Gulin, M. Vašak, and N. Perić, "Dynamical optimal positioning of a photovoltaic panel in all weather conditions," *Appl. Energy*, vol. 108, pp. 429–438, 2013

Optimized tracking algorithms improvement is location-dependent for bifacials, and locations at higher-latitudes and greater diffuse irradiance content can show more gain



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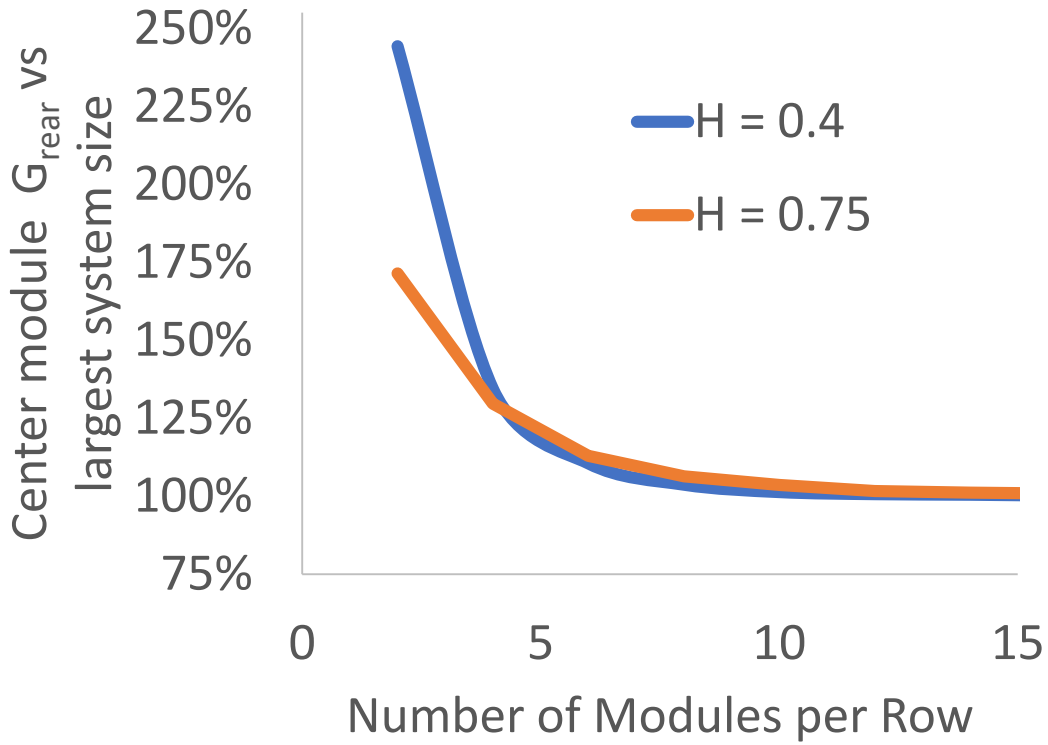
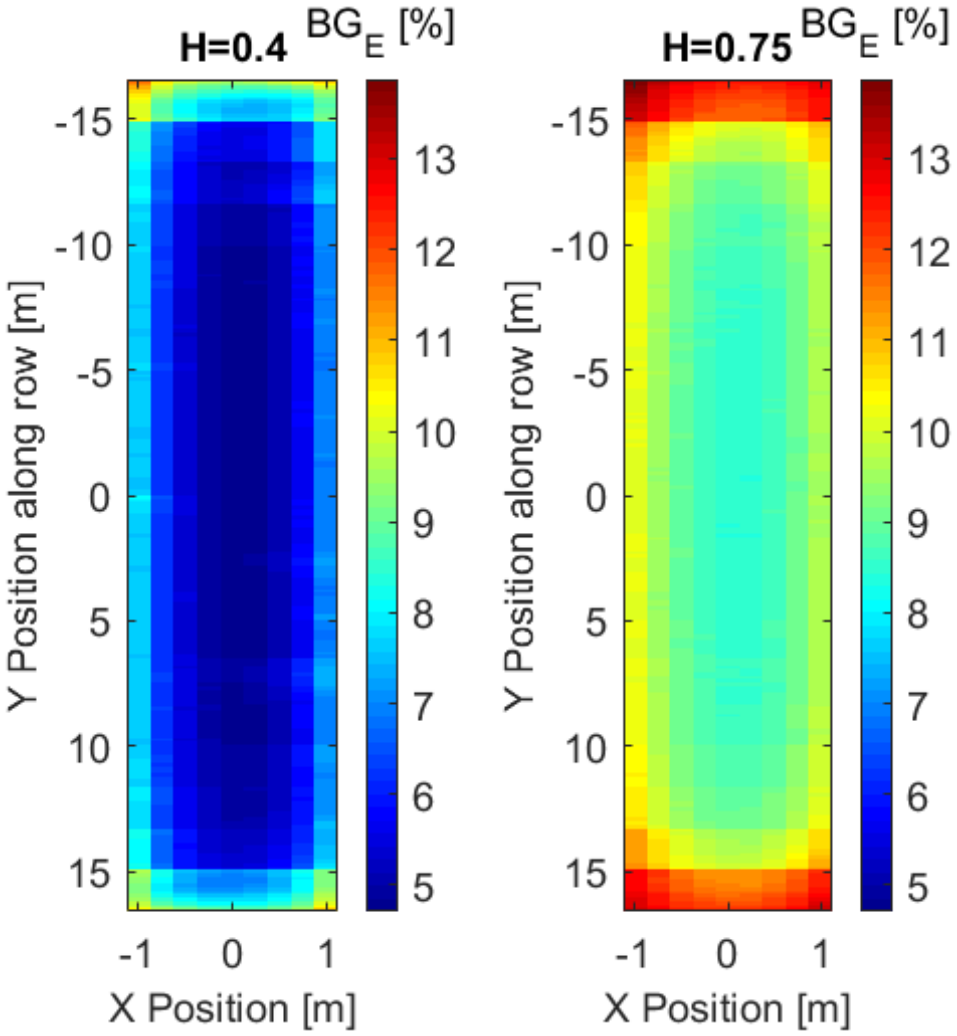
Edge effects

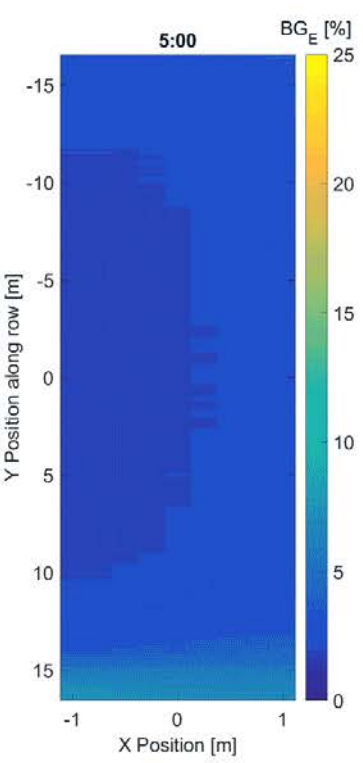
5 rows with 10 modules brings the G_{rear} within 5% of a semi-infinite assumption.



Within a distance of 5 m from the row edge, rear irradiance and BG_E is increased by 25% on the south edge, and 10% on the north edge.



June 21st row shading and BG_E modeling by hour



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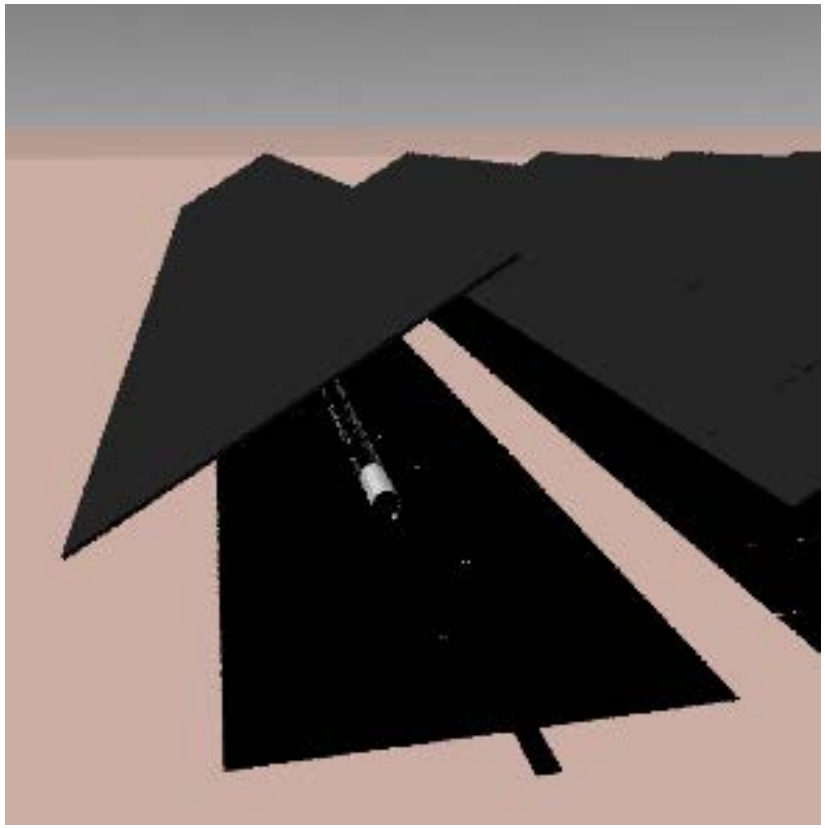
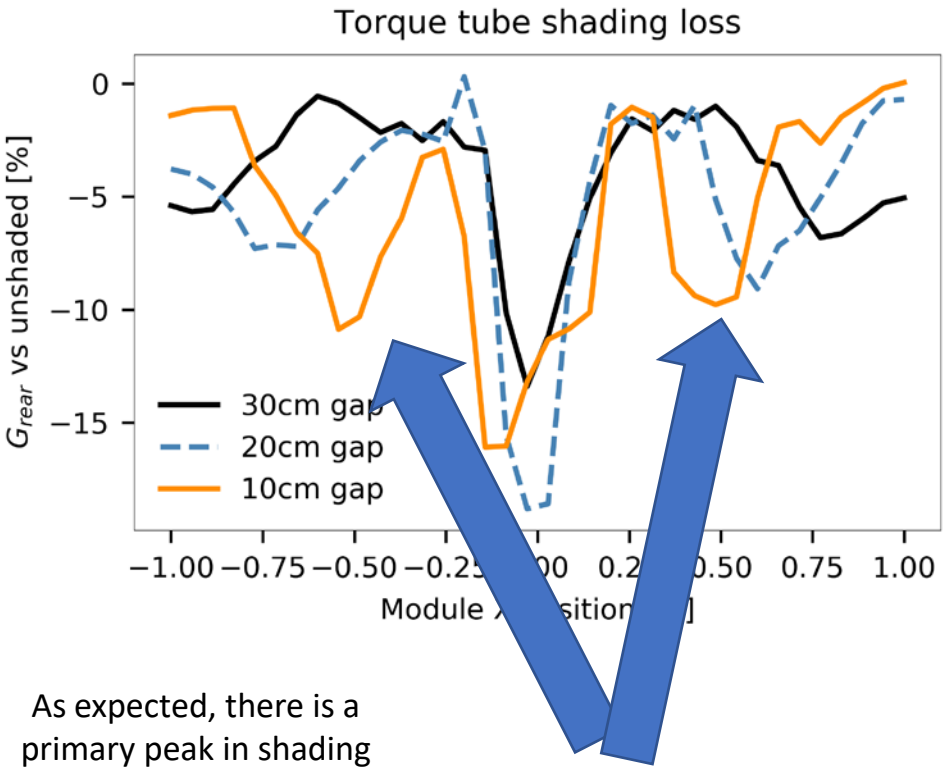
Tube Shading Loss





As expected, there is a primary peak in shading loss directly behind the tube at X = 0 m, reducing G_{rear} by 15% - 20%.

$$x_{shadow} = 0.5\ rtr\ \left[\left(1 - \frac{g+r}{H \cdot CW}\right)^{-1} - 1\right]$$

Summary Slide

1. Rear irradiance and available bifacial gain is dependent on available irradiance and location.
2. Isolating the bifacial response requires normalization of BG by modeled front-side performance PR_{model} for both module types.
3. Under cloudy conditions, bifacial gain can be improved by not tracking directly at the sun. The advantage increases with high albedo and for more diffuse climates.
4. The smaller the system, the less there will be mutual shading. So if you are running these models and comparing against field data, a large array system is needed to match the infinite assumptions.
5. Rack shading produces 15%-20% shading losses on rear irradiance that need to be considered and further studied.

Thank you. Questions?

Acknowledgements:
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